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# A SIMULATION ANALYSIS OF SPACE-BASED AND AIRBORNE MOVING PLATFORM RADARS IN LOOK-DOWN CLUTTER

AD-A133823

Paul L. Repak

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| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>RADC-TR-83-126 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>A SIMULATION ANALYSIS OF SPACE-BASED AND AIRBORNE MOVING PLATFORM RADARS IN LOOK-DOWN CLUTTER | | 5. TYPE OF REPORT & PERIOD COVERED<br>In-House Report |
| | | 6. PERFORMING ORG. REPORT NUMBER<br>N/A |
| 7. AUTHOR(s)<br>Paul L. Repak | | 8. CONTRACT OR GRANT NUMBER(s)<br>N/A |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Rome Air Development Center (OCTM)<br>Griffiss AFB NY 13441 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>62702F<br>45061766 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Rome Air Development Center (OCTM)<br>Griffiss AFB NY 13441 | | 12. REPORT DATE<br>May 1983 |
| | | 13. NUMBER OF PAGES<br>70 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)<br><br>Same | | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE<br>N/A |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Radar
Clutter
Simulation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A simulation technique has been developed to provide the radar engineer with a tool for comparative examination of radar systems and target detection in the presence of look-down clutter. Using a plotting interface such as the Dedicated User Interface System (DUIS), an engineer can evaluate proposed radar designs against one another for target detection performance in a precise graphical format.

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The user is able to select an antenna function from either measured data or derived data under the existing Parametric Antenna Analysis Software (PAAS). The antenna platform may be at any designated altitude and velocity with respect to ground clutter scatterers. Entry of an exoatmospheric altitude automatically computes the proper circular satellite orbit velocity and introduces Earth rotation. Target radar echoes at specified ground locations are compared to clutter echoes in the sidelobes as well as the radar mainbeam. Analysis of output data serves as a measure of moving target minimum detectable velocity (MDV) for the total radar system.

Written for analysts with some technical doppler radar and clutter understanding this report leads the engineer through the theory and equations which develop the simulation computer program. Example cases and analyses are given to show program utility and output results.

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## INTRODUCTION

Analysis of radar detection performance in moving platforms, either in a satellite or aircraft, is a continuing area of interest. The need to detect smaller targets in look-down geometries, plus the expected difficulty of achieving deterministic low sidelobe patterns in space deployable antennas and for conformal antennas on various airframes has dictated a relook at the moving target detection design for such radar systems.
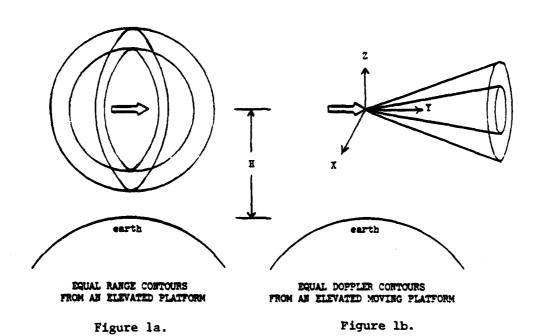
This report describes a simulation analysis computer program which examines the target detection performance of space based and airborne surveillance radars in look-down clutter. The computer model samples ground clutter with specified radar cross section and grazing angle effect and analyzes clutter signal power intensity as an effective area in range and range-rate (doppler) space. With included targets and antenna parameter data, a computed target to clutter ratio plotted for some range over all range-rates is shown as a means of measuring target minimum detectable velocity. A 3-D plot of clutter intensity as program output indicates how antenna systems may be compared with one another in terms of target detectability. The program is capable of plotting in 3-D format the clutter intensity or clutter to target ratio over all range and doppler which is visible to the antenna. The 3-D plots at a glance indicate the relative merit of given radar antenna systems.

General program parameters are developed with geometric consideration of both a non-rotating and a more complex rotating earth model. Current program limitations are discussed as well as continuing and future improvement efforts. Although this program is applicable to any set of monostatic antenna and platform parameters, a specific example is given as an illustrative example.

## RANGE-DOPPLER CELLS

The problem of computing range-doppler sample data from a moving platform is outlined in figures 1a and 1b. A range gated doppler radar analyzes the returned signal in both time (range) and frequency

(doppler). The signal is processed by first dividing it into a number of intervals in time (range gates) and then analyzed by passing it through a set of doppler frequency filters. The locus of points of equal range from a monostatic radar antenna which intersects the earth is called an isorange and is a circle centered about the platform subpoint. All such sampled ranges produce a series of concentric circles on the earth (figure 2a).



EQUAL RANGE CONTOURS
FROM AN ELEVATED PLATFORM

Figure 1a.

EQUAL DOPPLER CONTOURS
FROM AN ELEVATED MOVING PLATFORM

Figure 1b.

Unfortunately, the locus of equal range-rates intersecting the earth is not as easy to characterize. Relative to a moving platform the locus of points in space of equal doppler shift is a cone whose vertex is at the antenna, and whose axis coincides with the velocity vector of the platform. Intersection with the spherical earth results in a distorted conic section called an isodop. The maximum doppler component of ground clutter is thus the platform velocity relative to the earth multiplied by the cosine of the minimum cone angle which intersects the e -th (fip· e 1b). The zero doppler component will be at all range po... w... :h lie orthogonal to the velocity vector (neglecting rotating

earth effects).

The intersection of isoranges and isodops for a radar system with contiguous range gates and doppler filters is sketched in figure 2a. To limit the processing required, the radar clutter returns may be sampled at a finite number of ranges equally spaced from the minimum to the maximum expected range. The doppler data may also be sampled by a finite number of doppler filters equally spaced between maximum and zero doppler. The minimum width of the range gates may be taken down to the range resolution limit of the radar system. Similarly, the doppler filter bandwidth minimum limit depends on the radar system characteristics. The intersection of N isoranges with M isodops and their respective resolution widths define NxM range-doppler cells (see figure 2b). It is from these cells that the simulation clutter data is sampled and computed.
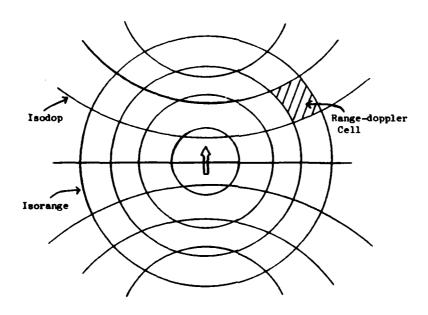


Figure 2a. Equal Range and Equal
Doppler Map on Earth's Surface
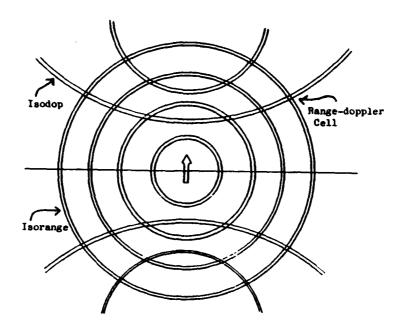
Figure 2b. Sampled Resolution Limited Map

## GEOMETRIC ANALYSIS
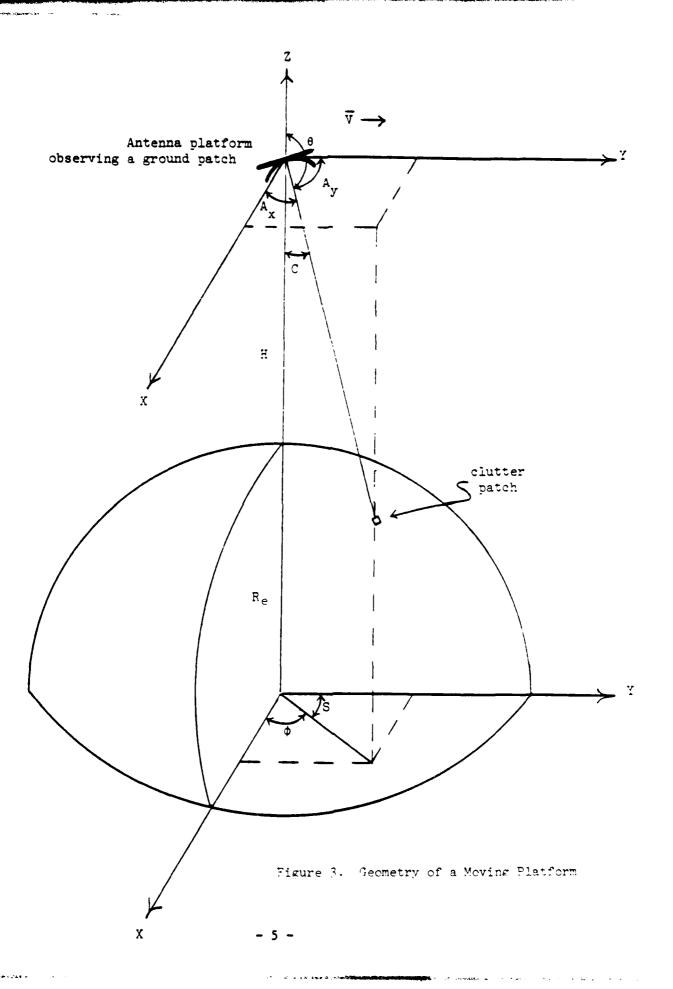
Figure 3 shows a moving platform radar antenna at a distance H above the earth's surface in a right hand coordinate system. A geometric analysis of figure 3 yields the equations necessary to calculate the range-doppler cells and their effective clutter contribution to the radar echo.

Any point in the far field of an antenna can be represented by a pair of direction cosines $T_x$ and $T_y$, where the relationship with spherical coordinate angles is:

$$T_x = \cos(A_x) = \sin(\theta)\cos(\phi)$$
$$T_y = \cos(A_y) = \sin(\theta)\sin(\phi)$$

It is convenient to place the moving antenna platform at the center of the coordinate system with the velocity vector $\bar{V}$ coinciding with the

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Figure 3. Geometry of a Moving Platform

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Y axis and the Z axis pointing up. The reference to a point on the ground may be given in terms of a vertical elevation angle C and an azimuthal scan angle S measured from V. The direction cosines are simply related by:

$$T_x = \sin(C)\sin(S)$$
$$T_y = \sin(C)\cos(S)$$

From figure 4a the elevation angle of the horizon, which is the complement of the minimum horizon cone angle $A_{ymin}$, and the range to the visible horizon $R_{max}$ are:

$$\sin(C_{max}) = \cos(A_{ymin}) = Re/(Re+H)$$

$$R_{max} = ((Re+H)^2 - Re^2)^{\frac{1}{2}}$$
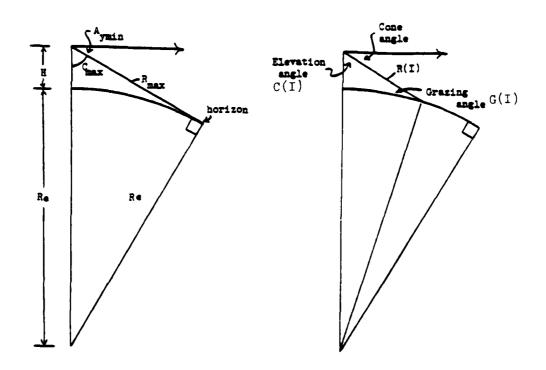


Figure 4a.
Geometry at the Horizon

Figure 4b.
Geometry at Intermediate Ranges

Similarly, for any given range R(I) corresponding to some range bin I, figure 4b and the law of cosines results in the elevation angle C(I):

$$C(I) = \arccos\left[\frac{R^2(I) + (R_e+H)^2 - R_e^2}{2R(I)(R_e+H)}\right]$$

The grazing angle G(I) at a particular range R(I) is given by figure 4b and the law of sines:

$$G(I) = \arccos\left[\frac{R_e+H}{R_e}\sin(C(I))\right]$$

Consider now the equally spaced sampled range and doppler bins of figure 2b. The distance between the N range bins is determined by dividing the total range difference by the number of range gates less one:

$$D_r = (R_{max} - H)/(N-1)$$

The range of the I$^{th}$ (I=1 to N) bin is calculated from:

$$R(I) = (I-1)D_r + H$$

where the nadir is at R(1)=H and the horizon is at R(I=N)=R$_{max}$.

To avoid the problems of clutter cell area on the horizon, for the purposes of the simulation the range difference is divided by N instead of N-1. This has the effect of decreasing D$_r$ slightly and placing the last range bin R(N) a small distance back from the horizon. If the range resolution of the radar is $\Delta$r, from figure 4b the effective ground range coverage for small $\Delta$r is $\Delta$r/cos(G(I)). Of course N must be chosen so that D$_r$ is significantly larger than this value to prevent range overlapping in the range bins of interest.

The M equally spaced doppler bins are equivalently computed from the radial velocity components, since the two way radar doppler shift is proportional to the radial velocity seen at the antenna platform and the wavelength of the radar operating frequency:

$$F_d = 2V_r/\lambda$$

where the radial velocity component is related to the platform velocity (for a stationary earth):

$$V_r = V_p \cos(A_y)$$

Then the frequency difference between the M equally spaced doppler filters, and the cone angles which yield the M isodops are:

$$D_f = 2V_p \cos(A_{ymin})/M\lambda$$

$$A_y(J) = \arccos(JD_f \lambda/2V_p) \qquad J=1 \text{ to } M$$

If the doppler filter width is $\Delta f$, then the angles which yield the N isodops of width $\Delta f$ are between $A_y(J)$ and:

$$A_{yd}(J) = \arccos((JD_f + \Delta f)\lambda/2V_p)$$

A critical factor arises at this point in the calculations. Since a cosine function has its most rapid change at large angles, most of the equally spaced doppler bins will be crowded at cone angles greater than 45 degrees away from the velocity vector. By the same reasoning, the ground coverage due to these angles is larger for smaller cone angles (i.e. close to the plane of motion near the horizon). In effect the area of the range-doppler bins of figure 2b becomes larger as the plane of motion is approached.

Now the clutter intensity in the radar echo will be a function of the area of the range-doppler cells in figure 2b. From here on a simplifying assumption must be made concerning the shape of the range-doppler cells. As long as the resolution width of the range bins and doppler bins is small compared to the distance between them, each cell can be approximated as a rectangular area. The radial component is a simple function dependent on the grazing angle and range resolution, but the lateral component requires a somewhat more complicated geometric

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analysis of the vectors which define the isodops and their equivalent resolution widths at each range.

## CLUTTER INTENSITY DIAGRAM

Consider the case of continuous scatterers uniformly distributed on the earth's surface and a radar with infinitely fine resolution. If the radar is unambiguous in both range and doppler, the clutter scatter signal strength $C(r,\dot{r})$ will be a function of at least four components. First is the $1/R^4$ two way path loss attenuation factor from the radar range equation. Second is the radar cross section $\sigma_0$, of the ground scatterers. Several models are available which describe ground RCS as a function of terrain type and grazing angle. The third component is the two way relative antenna gain as a function of directional cosines $T_x$ and $T_y$. The directional cosines correspond to those angles which yield r and $\dot{r}$ at the earth's surface. Finally, the area of the range-doppler cells must be computed which will determine the number of discrete scattering centers, providing the integrated clutter signal power.

Presuming for the moment an omnidirectional antenna with unity gain and uniformly distributed range-doppler scatterers, the clutter intensity diagram takes on the smoothly shaded appearance of figure 5a. Range R is plotted along the ordinate axis and the direction cosine angle $A_y$ is plotted on the abscissa. Dark shading represents regions of high clutter echo intensity (integrated radar return signal power).

The distinctive "U" shape of the expected clutter return of figure 5a is strictly a function of platform altitude and earth radius. Outside this shaded area is a clutter free region where no combination of range and cone angle intersect the earth's surface and in this region a target would not compete with surface clutter. Directly beneath the antenna platform corresponds to a zero degree elevation angle and 90 degree cone angle, with range equal to platform altitude (figure 1b). Progressing outward in range one reaches the radio horizon, which is the range of the visible horizon from the elevated antenna platform. Greater ranges would correspond to range-doppler cells which do not intersect the earth. Range excursion along the central vertical of figure 5a at a constant 90 degree cone angle is a vertical scan in

elevation orthogonal to the plane of motion, while travel along the "U" edge is a vertical scan in the plane of motion. A depiction of the relationship between a pencil beam antenna footprint and the clutter intensity diagram is shown in figure 5b. Notice that near the edge, close to the plane of motion, the intensity rises due to the increased area size of the range-doppler cells. Since the cell area is larger, effectively more point scatterers are covered per cell resulting in a greater power intensity.
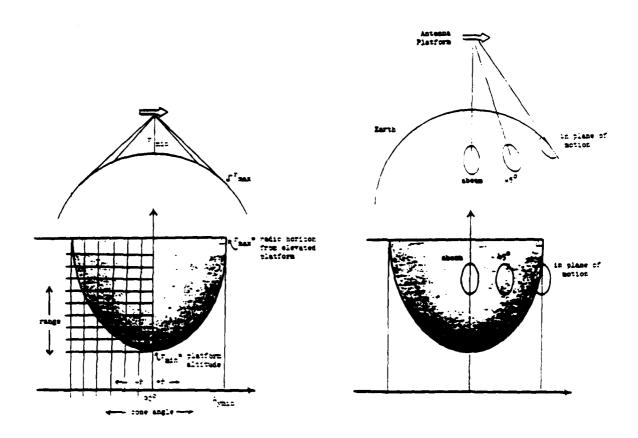


Figure 5a.

Clutter Intensity Diagram C(r,ṙ)

Figure 5b.

Relationship Between a Pencil Beam Antenna
Footprint and the Clutter Intensity Diagram

Now consider a somewhat more realistic antenna with finite range resolution $\Delta r$ and finite doppler resolution $\Delta r$ corresponding to discrete noncontiguous range-doppler cell scatterers. The clutter scatter function for each cell is depicted in figure 6. This discrete characterization of the distributed returns $C(\Delta r, \Delta \dot{r})$ for the $I^{th}$ specific range bin and the $J^{th}$ specific doppler bin is used in the computer program simulation. The clutter scatter function of each cell is an integral over the range and doppler cell widths.

$$C_{i,j}(\Delta r, \Delta \dot{r}) = \int_{r_i - \Delta r/2}^{r_i + \Delta r/2} \int_{\dot{r}_j - \Delta \dot{r}/2}^{\dot{r}_j + \Delta \dot{r}/2} C(r_i, \dot{r}_j) dr_i d\dot{r}_j$$
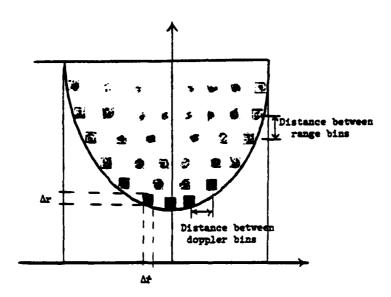


Figure 6.
Clutter Intensity Diagram
Discrete Scatterer Case $C(\Delta r, \Delta \dot{r})$

For an unambiguous range gated pulse doppler radar with a known far field antenna pattern weighting (including sidelobes) as a function of directional cosines, one only needs to multiply the discrete clutter by the weighting function $ANT(T_x, T_y)$ to obtain the clutter intensity function of the antenna.

# DIRECTING THE ANTENNA

The question of directing the antenna main beam toward some specified point on the earth's surface must be addressed. In a phased array this is accomplished by electronic beam steering, which simply redefines the weighting function $ANT(T_x, T_y)$. Alternatively, the antenna platform may be mechanically steered in roll, pitch, and yaw as defined in the right hand coordinate system of figure 7.
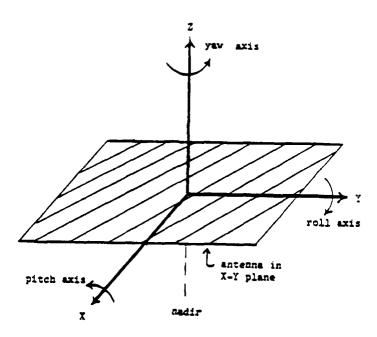


Figure 7.

Coordinate Transformation Axes

Mechanical steering is accomplished by applying the Jacobian matrix:

$$
\begin{bmatrix} T'_x \\ \\ T'_y \end{bmatrix} = \begin{bmatrix} \cos(pit)\cos(yaw) & -\cos(pit)\sin(yaw) \\ \\ \sin(rol)\sin(pit)\cos(yaw)+\cos(rol)\sin(yaw) & -\sin(rol)\sin(pit)\sin(yaw)+\cos(rol)\cos(yaw) \end{bmatrix} \begin{bmatrix} T_x \\ \\ T_y \end{bmatrix}
$$

(From Mathematical Handbook for Scientists and Engineers, Korn and Korn, 2nd ed., McGraw Hill, 1968)

where the primed coordinates are in the steered frame of reference. These new directional cosines are input to the modified weighting function $ANT(T_x', T_y')$. The antenna has been effectively steered toward the specified patch of earth.


ROTATING EARTH MODEL

Up to this point the effects of the rotating earth have been neglected. This assumption is valid for airborne antenna platforms which are in a rotating earth frame of reference, but the motion of space based radar platforms is independent of earth rotation and the earth will provide a component of doppler velocity. Consider a platform stationary in space with the earth rotating beneath as sketched in figure 8.
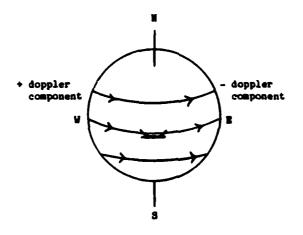
Figure 8.
Rotating Earth Doppler Components


Clearly for an orbiting platform, the earth's doppler velocity component will be negative when looking in the eastern hemisphere, positive in the western hemisphere, and zero along the central meridian. Of course, to the earth component radial velocity must be added the radial component due to the orbital velocity of the satellite. Note that the line of zero total doppler velocity will no longer be precisely orthogonal to the velocity vector (except in an equatorial orbit). In

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general for a moving platform in circular orbit, the radial doppler velocity component depends on altitude, orbit inclination, and the grazing angle of the ground clutter patch. In the simulation of a range-doppler cell radar system the total radial velocity component from each of the individual cells is given by:

$$V_r(I,J) = V_p \cos(A_y) - V_e \cos(G)\cos(lat)\cos(scan)$$

$$scan = \arccos(\cos(A_y)/\sin(C)) - \arccos(\cos(inc)/\cos(lat))$$

where $A_y$ is a function of I and J; G and C are functions of I; "inc" is orbital inclination; "lat" is instantaneous satellite sub-latitude; and $V_e$ is the equatorial rotational velocity of the earth. The term "scan" is essentially the azimuthal scan angle measured from the satellite's instantaneous velocity vector.

The maximum total doppler velocity component will be at the horizon in the plane of motion. (Actually, depending on the position of the velocity vector, the rotating earth may change this maximum component direction, but for circular orbits up to geosynchronous altitudes the effect is small.)

$$V_{rmax} = V_p \cos(A_{ymin}) - V_e \cos(inc)$$

The velocity differential between each of the M equally spaced doppler bins is thus:

$$V_{diff} = V_{rmax}/M$$

and the doppler velocity of the $J^{th}$ doppler bin is:

$$JV_{rmax}/M = V_r(I,J)$$

Solving for the cone angles $A_y(I,J)$ which yield the desired equally spaced doppler bins results in a considerably more complex function than for the nonrotating earth model because of the combined I,J dependence.

$$\cos(A_y(I,J)) = \frac{DV1 \cdot DV2 \pm DV3 \cdot SQV \cdot \sin(C(I))}{DV2^2 + DV3^2}$$

where:

$$DV1 = (V_p \cos(A_{ymin}) - V_e \cos(inc))J/M$$

$$DV2 = V_p - V_e \cos(inc)/\cos(A_{ymin})$$

$$DV3 = (\cos^2(lat) - \cos^2(inc))^{\frac{1}{2}} V_e /\cos(A_{ymin})$$

$$SQV = \left[ DV2^2 + DV3^2 - DV1^2/\sin^2(C(I)) \right]^{\frac{1}{2}}$$

If the doppler filter bandwidth is $\Delta f$, then the angles which yield the N isodops of width $\Delta f$ are between $A_y(I,J)$ and:

$$A_{yd}(I,J) = A_y(I,J)\Big|_{DV1=DV1 + \Delta f \lambda /2}$$

Care must be exercised when applying these equations to take into account the direction of orbit and whether the antenna is pointed toward the northern or southern hemisphere. For the nonrotating earth case ($V_e = 0$), or for the satellite subpoint over a pole (inc=90, lat=90) the equations reduce to the simpler form previously derived.

## THE CLUTTER SIMULATION PROGRAM

The program CLUTR is designed for either a space based radar antenna in circular orbit or for an airborne platform in level flight. The antenna far field weighting input data resides in a file which either has been previously generated from PAAS (Parametric Antenna Analysis Software) or from an actual antenna data tape.

The inputs for a circular orbiting space based moving platform radar are:

  (1) The altitude above the earth's surface.
  (2) The range and doppler bin resolution size.
  (3) The radar operating frequency.
  (4) The orbit inclination and platform sub-latitude.
  (5) The direction of orbit, east or west.
  (6) The main beam pointing quadrant, north or south.

(7) The antenna roll, pitch, and yaw pointing angles.

(8) The target radar cross section.

(9) The far field antenna weighting values $ANT(I_x, I_y)$.

Inputs for an airborne platform are the same except items (4), (5), and (6) are omitted and an input ground speed is required. Figure 9 is a block diagram of the basic components of the program.
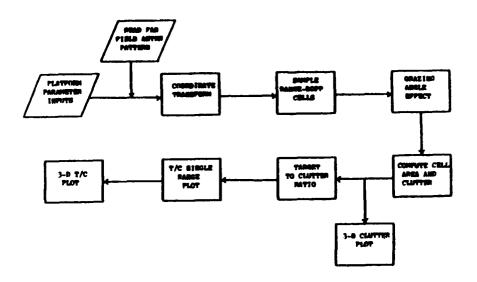


Figure 9.

Program CLUTR Block Diagram

The data from two auxiliary programs are required for inputs to the main program CLUTR. This is to insure that the radar main beam falls within one of the sampled range-doppler cells. Program RANGE provides a listing of range bin numbers with range $R(I)$, elevation angle $C(I)$, and grazing angle $G(I)$ for each range bin I. Given a desired grazing angle, for example, the range bin number yielding the nearest grazing angle is selected. This grazing angle and corresponding elevation angle value must be entered into CLUTR and will center the main beam in range I. Program SCAN provides a listing of azimuthal scan angle $S(I,J)$ and cone angle $A_y(I,J)$ for each doppler bin J at the range I. The value $S(I,J)$ centers the main beam in doppler bin J.

EXAMPLE CLUTTER PROGRAM RUN

The utility of the simulation is best demonstrated with an example case. Consider first an omnidirectional antenna (i.e. all $T_x$ and $T_y$ antenna weighting values are unity) with the antenna platform in a 4000 nautical mile high circular orbit. Samples of 128 range bins and 128 doppler bins are taken, resulting in 128 range-doppler cells. The 3-D sampled clutter intensity diagram output is shown in figure 10. Notice that figure 10 is just one half of figure 6, with the inter-cell spaces compressed. The ragged edge is an artifact of the sampling process, as no samples are taken exactly in the plane of motion, but the distinctive "U" shape is clearly evident.
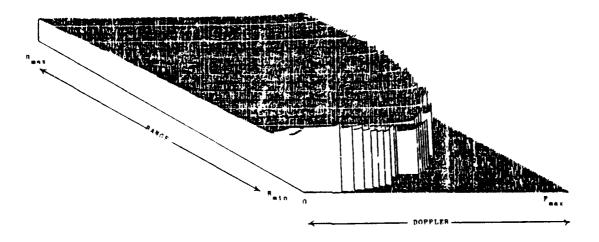


Figure 10.

3-D Omnidirectional Antenna Clutter Intensity

Next consider PAAS generated far field weighting for the following hypothetical antenna system:

Diameter - 35m circular

Weighting - 40dB Taylor

Blockage - None

Wavelength - L Band

Range Resolution - 100m

Doppler Filter Bandwidth - 50Hz

Element Grid Spacing - .5$\lambda$

The central portion of the far field antenna pattern is shown in figure 11.
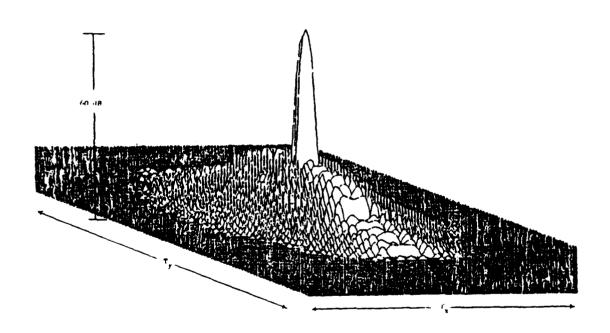


Figure 11.

40 dB Taylor Far Field Antenna Pattern

Now place the antenna aboard an orbiting platform with the following observation characteristics:

     Altitude - 4000 nautical miles

     Inclination - 60 degrees

     Sub-latitude Point - 20 degrees

     Main Beam Scan - True north (000 degrees true)

     Desired Main Beam Grazing Angles - 5 degrees and 30 degrees

     Target RCS - 20dBsm

From the auxiliary program output RANGE, the grazing angle closest to $30^\circ$ is $30.049^\circ$, corresponding to an elevation angle of $23.59^\circ$ at range bin number 55. Similarly from the same output listing, a grazing angle of $4.84^\circ$ is in range bin number 115 with an elevation of $27.43^\circ$. The antenna is steered by providing the elevation angle as a roll or pitch angle.

```
FRN RANGE

INPUT THE ALTITUDE IN NM
=4000.

ALTITUDE  =  0.74080000E 07     METERS
RMAX      =  0.12217659E 08     METERS
CEEMAX    =  0.27540163E 02     DEGREES

  I      RANGE(I)         CEE(I)          GRAZ(I)

 110   1.1503725E 07   27.3402605E 00   66.3459975E-01
 111   1.1541301E 07   27.3613958E 00   62.7339971E-01
 112   1.1578876E 07   27.3812790E 00   59.1364515E-01
 113   1.1616452E 07   27.3999195E 00   55.5539829E-01
 114   1.1654027E 07   27.4173350E 00   51.9357126E-01
 115   1.1691603E 07   27.4335396E 00   48.4312826E-01
 116   1.1729178E 07   27.4485452E 00   44.8307173E-01
 117   1.1766754E 07   27.4623659E 00   41.3635564E-01
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 119   1.1841905E 07   27.4865022E 00   34.3485792E-01
 120   1.1879480E 07   27.4968429E 00   30.8604759E-01
```

Sample Output Program RANGE
$5^\circ$ Grazing Angle Case

At this point in the orbit, the velocity vector heading relative to true north is:

$$HDG = \arcsin(\cos(inc)/\cos(lat))$$
$$= 32.15 \text{ degrees}$$

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Thus to scan to a true heading of 000 degrees a steering yaw of $32.15^\circ$ is required. From the auxiliary program output SCAN, the nearest scan angle for the 55th range bin is $32.718^\circ$ in the 103rd doppler bin; for the 115th range bin it is $32.232^\circ$ in the 119th doppler bin.

```
FRN SCAN

INPUT THE ALTITUDE IN NM
=4000.

ALTITUDE    =  0.40000000E 04  NM
ORBITAL VELOCITY  =  0.53814546E 04  M/S
ORBITAL VELOCITY  =  0.10460711E 05  KNOTS

INPUT SATELLITE INCLINATION ANGLE
AND INSTANTANEOUS LATITUDE
=60.,20.
IF FLYING EAST ENTER E
IF FLYING WEST ENTER W
=E
IF LOOKING IN NORTH QUADRANT ENTER N
IF LOOKING IN SOUTH QUADRANT ENTER S
=N
ENTER THE RANGE BIN NUMBER
TO SEE ALL DOPPLER COMPONENTS AT THAT RANGE
=115

VECTOR HEADING  =  0.32146700E 02   DEGREES

   J        ALPHA(I,J)        SCAN(I,J)        VDOP  KTS

  114     58.5241127E 00     37.3780093E 00     3.9066537E 03
  115     58.2395792E 00     36.4217615E 00     3.9409225E 03
  116     57.9515810E 00     35.4333115E 00     3.9751914E 03
  117     57.6597738E 00     34.4088478E 00     4.0094603E 03
  118     57.3637439E 00     33.3437486E 00     4.0437292E 03
  119     57.0629845E 00     32.2323437E 00     4.0779980E 03
  120     56.7569665E 00     31.0675187E 00     4.1122670E 03
  121     56.4445915E 00     29.8401928E 00     4.1465358E 03
  122     56.1251125E 00     28.5383661E 00     4.1808047E 03
  123     65.7970142E 00     27.1457679E 00     4.2150737E 03
  124     55.4582968E 00     25.6392046E 00     4.2493425E 03
```

Sample Output Program SCAN

$5^\circ$ Grazing Angle Case

Figure 12 is a 3-D plot of the antenna pattern weighted clutter intensity diagram for the $5^\circ$ grazing angle case. The main beam clutter region is clearly defined (centered at range bin number 115 and doppler bin number 119), although it is smeared in range near the horizon. At low grazing angles such as this, even if the main beam has relatively narrow angular beamwidth, it will cover many range clutter cells due to the curvature of the earth. Again the "U" shape similar to figures 5a and 10 is apparent, with most of the clutter along the doppler edge. Even though the main beam is pointed well out in range and the sidelobes are very low, there is some close in clutter do to (1) the $1/R^4$ factor
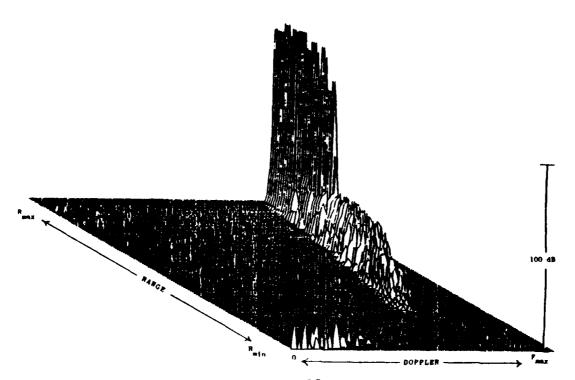
Figure 12.

3-D Clutter Intensity Plot
5° Grazing Angle
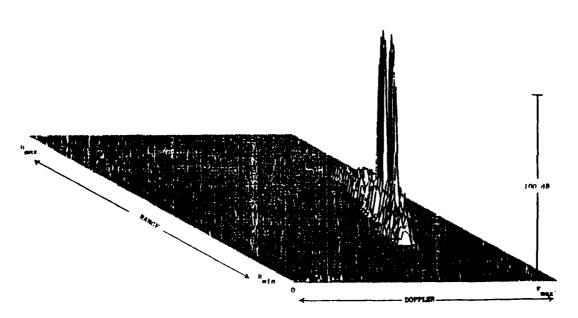


Figure 13.

3-D Clutter Intensity Plot
30° Grazing Angle

which has much less effect for small R, and (2) the grazing angle effect which increases the ground patch clutter RCS for near ranges.

A similar plot in figure 13 is for the 30° grazing angle case. Here the beamwidth on the ground is relatively narrow and the sidelobes still contribute to the near range clutter, although performance is better because there is not such a large difference between the range of the main beam clutter and the nadir.

ANTENNA WITH BLOCKAGE

Consider the same PAAS generated antenna pattern, only this time with a 5% central blockage. The far field pattern is shown in figure 14. Notice that the blockage has significantly degraded the sidelobe structure so that this antenna would be expected to have degraded off axis clutter suppression.
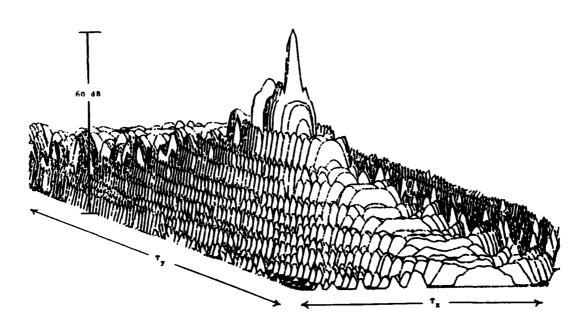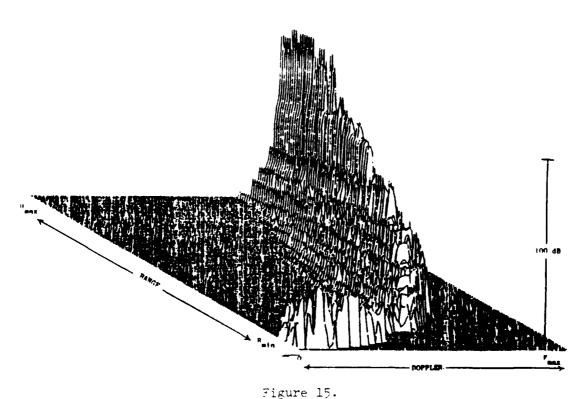
Figure 14.

40 dB Taylor Far Field Antenna Pattern
With 5% Central Blockage

Figure 15 is a 3-D plot of the clutter intensity diagram for the 5° grazing angle case with the blockage antenna. The general form is, as expected, the same as figure 12 but a considerable amount of sidelobe clutter has been introduced. Figure 16 is similarly a degraded version of figure 13.

Figure 15.

3-D Clutter Intensity Plot With Blockage
5° Grazing Angle

Figure 16.

30° Grazing Angle
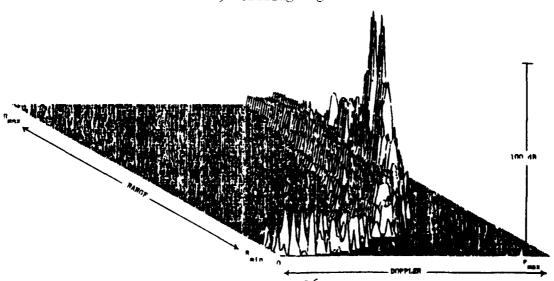
## MINIMUM DETECTABLE VELOCITY

The target to clutter ratio output of CLUTR for the 55th range bin over all doppler bins is plotted in figure 17a and expanded in figure 17b. Output for the 115th range bin is plotted in figures 18a and 18b.
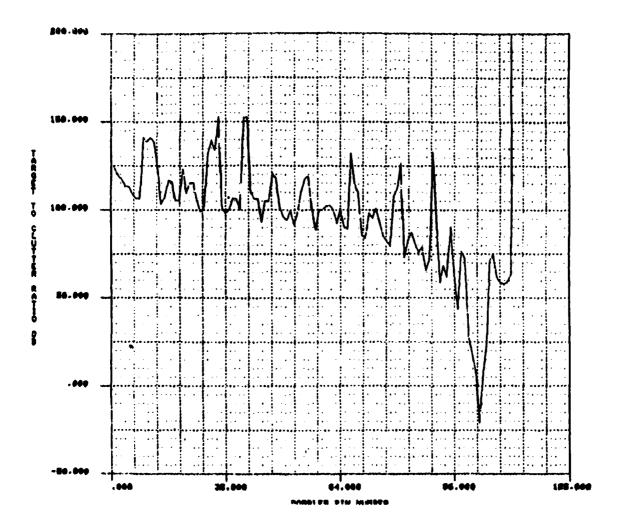


Figure 17a.

Target to Clutter Ratio Versus Doppler Bin
30° Grazing Angle
Range Bin 55
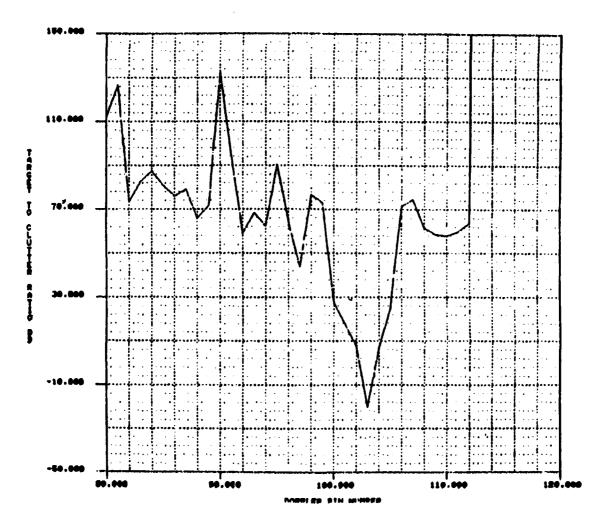
Figure 17b.

Target to Clutter Ratio Versus Doppler Bin
30° Grazing Angle
Range Bin 55
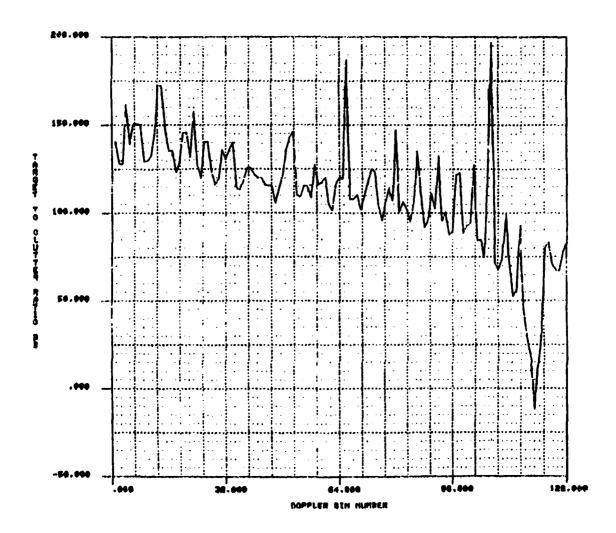
Figure 18a.

Target to Clutter Ratio Versus Doppler Bin
$5^{\circ}$ Grazing Angle
Range Bin 115
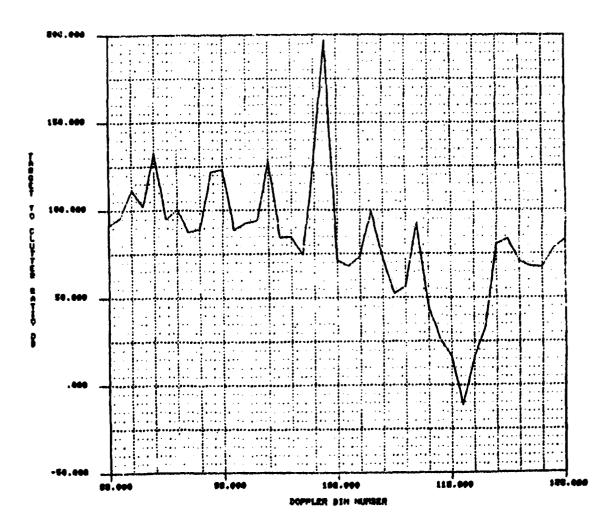
Figure 18b.

Target to Clutter Ratio Versus Doppler Bin
5° Grazing Angle
Range Bin 115

Notice that the minimum plot value falls in the 103rd doppler bin for the 55th range bin of figure 17b. This doppler bin corresponds to the radar return of a target which is stationary with respect to the earth. The rise to an infinite target to clutter ratio at doppler bin 112 corresponds to cone angle (target doppler) and elevation angle combinations which do not intersect the earth and hence the target does not compete with any clutter (clutter free region). Similarly, in figure 18b the stationary target minimum value falls in doppler bin 119.

The fixed clutter echoes with which the desired target signal must compete are those included within the same radar resolution cell as the target, or those which enter the receiver via the antenna sidelobes. To interpret the above plots in terms of minimum detectable velocity, note that the minimum value of the target to clutter ratio corresponds to a stationary target (relative to the earth) located in the same range-doppler cell as the clutter patch that the main beam is pointed to. This cell location is set to zero relative velocity between ground and target. Thus, in order to detect a stationary target a hypothetical receiver would require a detectability of better than -20dB at a $30^\circ$ grazing angle and better than -12dB at a $5^\circ$ grazing angle. However as the target's radial velocity increases, detectability performance increases markedly. Each doppler bin number is equivalent to a radial velocity difference of 34.3 knots (another output of SCAN), which is constant over all range bins. At a $30^\circ$ grazing angle, with a target velocity of +64.6 knots (two doppler bins) the receiver detectability requirement jumps to a more reasonable value of 25dB. Similarly at a $5^\circ$ grazing angle, a target velocity of +64.6 knots increases the requirement to 32dB.

A composite of all 128 target to clutter ratio range bins produces the 3-D clutter to target ratios of figures 19 and 20. As clutter is the dominant factor and the target RCS is nonfluctuating, the 3-D clutter to target ratio plots are near copies of their respective 3-D clutter plots.
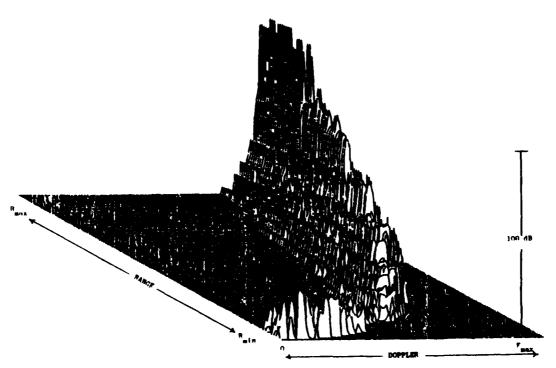
Figure 19.

3-D Clutter to Target Ratio
$5^{\circ}$ Grazing Angle
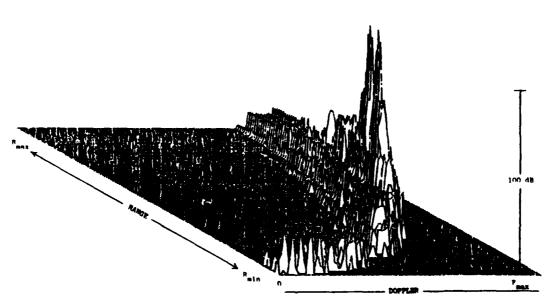
Figure 20.

3-D Clutter to Target Ratio
$30^{\circ}$ Grazing Angle

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## LIMITATIONS

The waveform characteristics are not included in the simulation model. There are two consequences of this limitation. First, the total energy transmitted in the radar range equation is unknown and as a result there can be no absolute level set on probability of detection of any given radar system; only the ratio of target to clutter return signal. Second, the particular shape of the waveform determines the resolution size (above that already determined by the physical antenna parameters) and the ambiguity function. The true radar return signal will be the convolution of the clutter intensity diagram and the ambiguity function.

The minimum detectable velocity is computed radial to the antenna platform, and as such the actual velocity of the target over the ground may be much larger in specific cases. This is especially true for large grazing angles where the target is illuminated from overhead. Dividing by the cosine of the grazing angle will in some sense result in a minimum ground speed in the radial plane.

The simulation presumes a "snapshot" radar image, and then only at designated sampled range-doppler cell positions. The intersection of the beam with the ground for a moving platform is a dynamic process (even more so for a moving target) which in a real system must be considered over an interval of time. Additionally, the target RCS is assumed nonfluctuating and independent of aspect angle.

The simulation program orbit is presumed circular. Many surveillance space radar applications, however, are in highly elliptical orbits. A minor program modification will handle elliptical orbits if the orbit's radial and tangential velocities are known.

To completely describe the far field antenna pattern of a radar system requires an enormous amount of computer memory space. The pattern can only be sampled at a finite number of discrete points in T space. The quality of the program results depends to a large extent on the fidelity of the far field pattern and the extent to which the sidelobe structure is detailed.

## FUTURE DEVELOPMENT EFFORTS

The program CLUTR is in a continuous state of change and improvement. Current goals lead to inclusion of the radar waveform and eventual convolution with the ambiguity function. This will result in a true target to clutter ratio prediction for a given radar platform and will allow quantitative analysis of the system. The present program is only applicable to monostatic radars with no ambiguities, but the increasing importance and development of bistatic radar systems will dictate program expansion to bistatics capabilities as well. Ongoing future developments seek to expand the utility of the simulation with greater accuracy and a wider range of applications.


## CONCLUSION

A major problem in designing a radar system with look-down capability is determining target detectability in the presence of ground clutter. The simulation analysis program is useful for the designer of a range gated pulse doppler to determine the clutter levels with which a target in a given cell must compete for detection. The results, while only a model and subject to certain limitations, should be most useful for comparing various candidate radar systems in the early concept stages. Considerable engineering savings in time and cost may be realized by the early elimination of inferior candidate antenna/platform system designs. The procedure described in this report should lead to more efficient radar system tradeoff analyses for the design engineer.

APPENDIX - I

Listing of Program CLUTR

```
C     A SIMULATION ANALYSIS OF SPACE-BASED AND AIRBORNE MOVING
C     PLATFORM RADARS IN LOOK-DOWN CLUTTER
C
C     TO RUN, ATTACH PLOTD.F FILE
C
C     VARIABLES:
C
C     RE     = RADIUS OF THE EARTH
C     HGT    = ALTITUDE OF THE PLATFORM
C     VEL    = VELOCITY OF THE PLATFORM
C     VE     = EARTH ROTATIONAL VELOCITY
C     XLAM   = WAVELENGTH
C     RMAX   = MAXIMUM RANGE
C     DELR   = DISTANCE BETWEEN RANGE BINS
C     DELTAR = RANGE BIN WIDTH
C     DELT   = DISTANCE BETWEEN DOPPLER BINS
C     DELTF  = DOPPLER BIN WIDTH
C     ALPHA  = ANGLE B/N VELOCITY VECTOR AND VECTOR TO POINT ON GROUND
C     ALPHAM = MINIMUM ANGLE ALPHA
C     ANT    = ANTENNA PATTERN FACTOR
C     SF     = SCALE FACTOR
C     CEE    = ANGLE MEASURED FROM NADIR
C     IPJ, LRK = MAXIMUM NUMBER OF RECORD LENGTHS ACROSS TX AND TY
C     KWIDE  = NUMBER OF DISCRETE VALUES IN TX AND TY
C     XLAT   = SUBLATITUDE POINT OF SATELLITE
C     XINC   = ORBITAL INCLINATION ANGLE
C     QUAD   = NORTH OR SOUTH LOOKING QUADRANT
C     DIRE   = EAST OR WEST ORBIT DIRECTION
C     TMAXX,THINX = MAX AND MIN VALUES OF TX IN T PLANE
C     TMAXY,TMINY = MAX AND MIN VALUES OF TY IN T PLANE
C
C*************************************************************************
C
C     INPUT SECTION
C
C*************************************************************************
C
      DIMENSION ANT(256)
      COMMON/ANTRANS/A11,A12,A13,A21,A22,A23,A11P,A12P
      COMMON/ANTENX/ANTX(256,256),NBMAX,CTRUT
      COMMON/TRIG/SINC,COSAZ
      COMMON/TPLANE/TMAXX,TMINX,TMAXY,TMINY
      COMMON/RANGE/LPJ,KWIDE,RANGEX,RANGEY
      COMMON/CLUTTER/CRRDOT(128),TCRATIO(128)
      COMMON/ANGLE/ALPHA,ALPHAD,ICR
      COMMON/ANGLE/P(128),CEE(128),SIGMA(128),GRAZ(128)
```

```
05484        XLAM/.21/,DELTAR/.75./,DELTF/.20./,SV/1.0E30/,LRK/16/,LRK/16/,
06504        TMAXX/.20758/,TMINX/-.20921/,TMAXY/.20921/,TMINY/-.20758/.
0563         DATA Y/1HV/,N/1HN/,S/1HS/,E/1HE/,V/1HV/
05700C
0582  1030 FORMAT(V)
0590C
0640C  ATTACH OUTPUT DATA FILE FOR RTI AND 3-D PLOTTING
0600C        CALL ATTACH(27,"BHICLANCY/DATA.R",3,0,ISTAT,)
0610         CALL RANSIZ(27,128)
0620C
0630C
0640C
0650C  SET UP ANTENNA PATTERN FORMAT
0660         NBMAX = LRJ*LRK
0670         JWIDE = LRJ*16
0680         KWIDE = LRK*16
0690         RANGEX = TMAXX-TMINX
0700         RANGEY = TMAXY-TMINY
0710C
0720         WRITE(06,1000)" "
0730         WRITE(06,1000)"INSURE THAT MAX ANTENNA VALUES"
0740         WRITE(06,1000)"AND LIMITS ARE SET"
0750C
0760         WRITE(06,1000)" "
0770         ALTI=HGT/1852.0
0780         WRITE(06,1000)"ALTITUDE ="ALTI," NM"
0790C
0800         WRITE(06,1000)"DO YOU WISH TO CHANGE THE CIRCULAR ORBIT ALTITUDE ?"
0810         WRITE(06,1000)"ENTER Y OR N"
0820         READ(06,1000)RESP3
0830C
0840C  SET SPACE/AIR TRANSITION ALTITUDE
0850         NM=91.
0860         IF(RESP3.EQ.N) GO TO 14
0870C
0880         WRITE(06,1000)"INPUT THE NEW ALTITUDE IN NM"
0890         READ(05,1000)HNM
0900         HGT=HNM*1852.0
0910         VEL=1.9976E07*SQRT(1/(HGT+RE))
0920C
0930C  FOR ALTITUDES LESS THAN 90 NM, ASSUME AIRBORNE PLATFORM
0940         IF(HNM.GT.90.0) GO TO 81
0950         WRITE(06,1000)"INPUT AIRCRAFT'S GROUND SPEED IN KNOTS"
0960         READ(05,1000) GS
0970         QUAD=0.0
0980         DIRE=0.0
0990         XLAT=0.0
1000         XINC=0.0
1010         VEL=GS*0.5144444
1020C
1030         WRITE(06,1000)"GROUND SPEED ="VEL," M/S"
1040         GO TO 14
1050     81  WRITE(06,1000)"ALTITUDE ="HGT," METERS"
1060         WRITE(06,1000)"ORBITAL VELOCITY ="VEL," M/S"
1070C
1080     14  CONTINUE
1090         WRITE(06,1000)" "
1100C
1110C  INPUT SATELLITE ORBIT DATA
1120C  BYPASS SATELLITE DATA IF AIRBORNE PLATFORM
1130         IF(HNM.LT.90.0) GO TO 89
1140         WRITE(06,1000)"INPUT SATELLITE INCLINATION ANGLE"
1150         WRITE(06,1000)"AND INSTANTANEOUS LATITUDE"
1160         READ(05,1000)XINC,XLAT
1170         XINC=XINC*PI/180.0
```

```fortran
1180      XLAT=XLAT*PI/180.0
1190      CINC=COS(XINC)
1200      CLAT=COS(XLAT)
1210      CD=ARCOS(CINC/CLAT)
1220C
1230C     WRITE(96,1000)"IF FLYING EAST ENTER E"
1240      WRITE(96,1000)"IF FLYING WEST ENTER W"
1250      READ(98,1000)RESP
1260      IF(RESP.EQ.W)DIRE=-1.0
1270      IF(RESP.EQ.E)DIRE=1.0
1280C
1290      WRITE(96,1000)"IF LOOKING IN NORTH QUADRANT ENTER N"
1300      WRITE(98,1000)"IF LOOKING IN SOUTH QUADRANT ENTER S"
1310      READ(98,1000)RESP2
1320      IF(RESP2.EQ.N) QUAD=-1.0
1330      IF(RESP2.EQ.S) QUAD=1.0
1340      IF(XINC.LT.0.) QUAD=-QUAD
1350      UD=QUAD*DIRE
1360C
   89
1370      WRITE(96,1000) "INPUT TARGET RCS (M**2)"
1380      READ(95,1000) TRCS
1390C
1400C     SET FLAGS FOR DESIRED PLOTTING
1410      WRITE(96,1000)"ENTER 0 FOR 3-D CLUTTER, 1 FOR C/T 3-D PLOT"
1420      READ(98,1000)ICT
1430      WRITE(96,1000)"ENTER -1 FOR 3-D ONLY"
1440      READ(95,1000) ITD
1450      IF(ITD.EQ.-1) GO TO 413
1460C
1470      WRITE(96,1000)"INPUT 3 RANGE BINS TO BE PLOTTED"
1480      READ(95,1000)NR1,NR2,NR3
1490C
1500  413 CONTINUE
1510C
1520C     COMMON/GEOM/PI,RE,HGT,VEL,XLAM,DELTAR,DELTF,SF
1530C     COMMON/ANTENNA/ANTX,LRJ,LRK,TMAXX,TMINX,TMAXY,TMINY
1540C     COMMON/CLUTTER/CRRDOT,ALPHA,CEE
1550C
1560C
1570      CALL COORD
1580C
1590      CALL ANTEN
1600C
1610C
1620C**********************************************************
1630C     PROGRAM SECTION
1640C**********************************************************
1650C
1660C     COMPUTE THE MINIMUM CONE ANGLE WHICH INTERSECTS THE EARTH
1670C     AND THE RANGE TO THE HORIZON
1680C
1690      ALPHAM=(PI/2.)-ARSIN(RE/(RE+HGT))
1700      CAM=COS(ALPHAM)
1710C
1720C     COMPUTE EQUATORIAL ROTATIONAL VELOCITY
1730      VER=2*PI*RE/86400.0
1740C
1750C     CALCULATE CONSTANTS FOR LATER USE
1760      DV2=RE*RE/CINC/CAM
1770      DV3=SQRT((CLAT**2-CINC**2)/CAM**2
1780      DV3=SQRT(DV3)
1790      DV1=ARCOS(VEL*UNC)/120.0
1810      VV2=RE*PI*VE*UNC)/360
```

```
18200C      CALL GRZ(HGT,RE)
18300C
18500C
18700C
18800C
18900C CALCULATE C(R,RDOT) FOR EACH RANGE/DOPPLER BIN
19100C   I = RANGE LOOP
19100C   J = DOPPLER LOOP
19200? ENTER RANGE LOOP
19300    DO 72 I=1,128
19400    RI4=R(I)**4
19500    RI4SF=SF/RI4
19700    SINC=SIN(CEE(I))
1975?    COSAZ=COS(CEE(I))
19800C
19900C SET CLUTTER FLAG
2000     ICR=1
2010     IX=1
2020C
2020C
2030C COMPUTE TARGET TO CLUTTER RATIO
2030     TPVR=TRCS*RI4SF
2040C
2050C ENTER DOPPLER LOOP
2060     DO 70 J=1,128
2070     JX=J
2080C
2090C BYPASS CLUTTER AT NADIR
2100     IF(I.EQ.1) GO TO 717
2110C
2120C CALL ROTEAR(SINC,COSAX,$717)
2130C
2140C CALL AREA(RI4SF,CRRDOT,IX,JX,DELTAR,$717)
2150C
2160C CALL CWEIGHT(ALPHA,COSAX,TPVR,ICR,ICT,IX,JX,$521)
2170C
2180C 717 ZERO CLUTTER FLAG
2190C     ICR=0
2200C
2210C     GO TO 719
2220?
2230?  621 SET ZERO CLUTTER
2240     CRRDOT(J)=0.0
2250     TCRATIO(J)=0.0
2260C
2270C  719 RESET CLUTTER FLAG
2280C     ICR=1
2290C
2300C     GO TO 633
2310C
2320C  633 CONTINUE
2330C
2340     END OF DOPPLER LOOP
2353C
2360C
2370     WRITE(2,1) CRRDOT
2410     IF(III.EQ.1) GO TO 72
2414     IF(I.NE.NR1) GO TO 72
2450     IF(I.NE.NR1).AND.(I.NE.NR2).AND.(I.NE.NR3))GO TO 72
```

```
2460 4444  CALL PLOTD(ICRATIO,128,1,0,1,0,1,0,1,0)
2470      WRITE(06,1000) %%D'
2480      READ 1000,ISTAT
2490      IF(ISTAT.EQ.1) GO TO 4444
2510      PRINT-,'Type CR when Ready'
2500      READ 1000,RPLY
2520      CONTINUE
2530C
2540C 871  CALL DETACH(27,ISTAT;)
2550C      CALL DETACH(29,ISTAT;)
2560C
2570 72
2580C
2590      IF((ICT.NE.1).AND.(ICT.NE.0)) GO TO 142
2573      WRITE(06,1000) 'TYPE CTRL F BEFORE 3-D PLOTTING'
2599      WRITE(06,1000) 'NEXT RUN CONVER.F'
2600      IF((ICT.NE.0) GO TO 141
2610      WRITE(06,1000) 'THEN RUN DBCONVER'
2620 141  WRITE(06,1000) 'FOLLOWED BY PAAS.TEM'
2630 142  STOP
2640      END
2650C
2660C
2670C
2680C
2690C
2700C  SUBROUTINE COORD
2720C
2730C  ROUTINE TO TRANSFORM DIRECTIONAL COSINES COSAX AND COSAY
2740C  FROM HORIZONTAL COORDINATES TO ARBITRARY COORDINATES OF
2750C  KNOWN ROLL, PITCH, AND YAW
2760C
2770C  VELOCITY VECTOR ALONG Y AXIS
2780C  NADIR ALONG -Z AXIS
2790C
2800      COMMON/ANTRANS/A11,A12,A13,A21,A22,A23,A11P,A12P
2810      DATA PI/3.141592/
2820 1000 FORMAT(V)
2810C
2820C
2830C  INPUT ANTENNA DIRECTIONAL PARAMETERS
2840C  WRITE(06,1000) 'INPUT ROLL, PITCH, YAW   IN DEGREES'
2850      READ(05,1000)ROL,PIT,YAW
2860C
2870      WRITE(36,1000) 'INPUT ANTENNA ROTATION ANGLE (CCW++)'
2880C     READ(05,1000) ANTROT
2890C
2900      ROL = ROL*PI/180.
2910      PIT = PIT*PI/180.
2920      YAW = YAW*PI/180.
2930      ANTROT = ANTROT*PI/180.
2947C
2960C  COMPUTE COORDINATE TRANSFORMATION MATRIX VALUES
2970      A11 = COS(PIT)*COS(YAW)
2980      A12 = -COS(PIT)*SIN(YAW)
2990      A13 = SIN(PIT)
3000      A21 = SIN(ROL)*SIN(PIT)*COS(YAW)
3010      A22 = -SIN(ROL)*SIN(PIT)*SIN(YAW)+COS(ROL)*COS(YAW)
```

```fortran
3100C      SUBROUTINE ANTEN
3120C      READ ANTENNA PATTERN FROM INPUT FILE AND PLACE INTO
3130C      2-DIMENSIONAL LOOK-UP TABLE ANT(IX,JX)
3140C
3150C      COMMON/ANTENX/ANTX(256,256),NBMAX,CTRVT
3160       DIMENSION ANT(256)
3170       COMPLEX ANT
3180C
3190C      CALL ATTACH(29,'FF1ANTONIK/ANT;',3,0,ISTAT,)
3200       CALL RANSIZ(29,512)
3210C
3220C      DO 400 IX=1,NBMAX
3230       READ(29;IX+1)ANT
3240       DO 300 JX=1,256
3250       ANTX(IX,JX) = CABS(ANT(JX))
3260  300  CONTINUE
3270  400  CONTINUE
3280C
3290C      FIND THE ANTENNA WEIGHTING MAXIMUM VALUE
3310C      CTRVT=ANTX(137,1)**4
3320C      RETURN
3330       END
3340C
3350C ***************************************************
3360C
3370C      SUBROUTINE GRZ(HGT,RE)
3380C
3390C      CALCULATE ELEVATION ANGLE CEE FOR EACH RANGE INCREMENT
3400C      AND GRAZING ANGLE GRAZ
3410C      COMMON/ANGLE/R(128),CEE(128),SIGMA(128),GRAZ(128)
3420C      DATA PI/3.1415927/
3430C
3440C      COMPUTE RANGE BIN SPACING SUCH THAT THE LAST BIN IS PRIOR TO
3460C      THE HORIZON
3470C      RESQ=RE**2
3480       RHTSQ=(RE+HGT)**2
3490       RMAX=SQRT(RHTSQ-RESQ)
3500       DELR=(RMAX-HGT)/128.
3510C
3520C      THE FIRST ELEVATION ANGLE IS NORMAL TO THE EARTH
3530C      CEE(1)=0.0
3540C
3550C      DO 50 I=1,128
3560       R(I)=HGT+(FLOAT(I-1)*DELR)
3570       IF(I.EQ.1) GO TO 53
3580       CEE(I)=ARCOS((-RESQ+(R(I)*R(I))+RHTSQ)/(2.*R(I)*(RE+HGT)))
3590  53   CONTINUE
3600C      COMPUTE THE GRAZING ANGLE
3610       GRAZ(I)=ARCOS(((RE+HGT)/RE)*SIN(CEE(I)))
3620       GRAZDEG=GRAZ(I)*180.0/PI
3630C
3640C      GRAZING ANGLE EFFECT
3650C      IF(GRAZDEG.GT.60.0) GO TO 222
3660       IF(GRAZDEG.GT.15.0) GO TO 111
3670       SIGMADB=0.067*GRAZDEG-32.0
3680       GO TO 333
3690  111  IF(GRAZDEG.GT.60.0) GO TO 222
3700       SIGMADB=0.156*GRAZDEG-24.33
```

```
3740        GO TO 333
3760C
3750  222   IF(GRAZDEG.GT.90.0) GO TO 40
3770        SIGMADB=1.5*GRAZDEG-105.0
3780        GO TO 333
3790C
3800   40   SIGMA(I)=-31.62
3810        GO TO 50
3820  333   SIGMA(I)=10.0**(SIGMADB/10.0)
3830   50   CONTINUE
3840        RETURN
3850        END
3860C
3870C========================================================
3880C
3890C     SUBROUTINE ROTEAR(SINC,COSAX,")
3900C
3910C     COMPUTE ANGLES CORRESPONDING TO DOPPLER BINS
3920C
3930        COMMON/ROTATE/DV1J,DV2,DV3,VV2,3
3940        COMMON/CONE/ALPHA,ALPHAD,ICR
3950        COMMON/CONST/XLAM,XINC,DELTF,QD
3960C
3970C     COMPUTE FRACTIONAL DOPPLER VELOCITY
3980        DV1=FLOAT(J)*DV1J
3990        SQVSQ=VV2-(DV1/SINC)**2
4000C
4010C     TEST FOR INVALID ANGLE OFF EARTH
4020        IF(SQVSQ.LT.0.0) GO TO 91
4030        SQV=SQRT(SQVSQ)*QD
4040        XNUME=DV1*DV2+DV3*SINC*SQV
4050C
4060C     COMPUTE CONE ANGLE ALPHA
4070        ALPHA=ARCOS(XNUME/VV2)
4080C
4090C     COMPUTE SCAN ANGLE AND RELATIVE SCAN ANGLE
4100        SCAN=ARCOS(COS(ALPHA)/SINC)
4110        RSCAN=QD*SCAN
4120C
4130C     COMPUTE X DIRECTION COSINE
4140        COSAX=SIN(RSCAN)*SINC
4150C
4160C     NEGATIVE INCLINATION TEST
4170        IF(XINC.LT.0.0) COSAX=-COSAX
4180C
4190C     COMPUTE DIFFERENTIAL ANGLE ALPHAD
4200        DV1D=DV1-DELTF*XLAM/2.0
4210        SQVSQD=VV2-(DV1D/SINC)**2
4220        SQVD=SQRT(SQVSQD)*QD
4230        XNUMED=DV1D*DV2+DV3*SINC*SQVD
4240        ALPHAD=ARCOS(XNUMED/VV2)
4250        RETURN
4260   91   RETURN
4270        END
4280C
4290C========================================================
4300C
4310C     SUBROUTINE AREA(H14,F,CRKDOT,I,J,DELTAR,")
4320C
4330C     COMPUTE RANGE-DOPPLER CELL AREAS
4340C     AND THE CLUTTER INTENSITY CRRDOT
4350C
4360        COMMON/FCON /ALPHA,ALPH3D,ICR
4370        COMMON/ANGLE/R(120),CEE(120),SIGMA(120),GRAZ(120)
```

```
4380      DIMENSION CRRDOT(128)
4390C
4400C
4410      A=R(I)*SIN(CEE(I))
4420      SCL=0.
4430      XNUMB=0.
4440      CONTINUE
4450      B=R(I)*COS(ALPHA)
4460      C=A
4470      D=R(I)*COS(ALPHAD-(SCL*XNUMB))
4480   62 IF (C .GE. D) GO TO 69
4490      IF (A .LT. B) GO TO 71
4500      SCL=(ALPHAD-ALPHA)/10.
4510      XNUMB=XNUMB-1.
4520      GO TO 62
4530   69 IF (A .LT. B) GO TO 71
4540      SIX=SQRT((A*A)-(B*B))
4550      SIY=B
4560      SIZ=R(I)*COS(CEE(I))
4570      S2X=SQRT(((C*C)-(D*D)))
4580      S2Y=D
4590      S2Z=SIZ
4600      EX=(SIX-S2X)*(SIX-S2X)
4610      EY=(SIY-S2Y)*(SIY-S2Y)
4620      EZ=(SIZ-S2Z)*(SIZ-S2Z)
4630      CRRDOT(J)=(SQRT(EX+EY+EZ)*DELTAR/COS(GRAZ(I)))*SIGMA(I)
4640      CRRDOT(J)=CRRDOT(J)*R14SF
4650      RETURN1
4660   71 RETURN
4670      END
4680C
4690C**************************************************************
4700C**************************************************************
4710C
4720C     SUBROUTINE CWEIGHT(ALPHA,COSAX,TPWR,ICR,ICT,I,J,*)
4730C
4740C     ROUTINE TO WEIGHT CRRDOT BY COMPUTED ANTENNA PATTERN FROM
4750C     KNOWN VELOCITY VECTOR ANGLE ALPHA AND NADIR ANGLE CEE(I)
4760C
4770      COMMON/TPLANE/TMAXX,TMINX,TMAXY,TMINY
4780      COMMON/TRIG/SINC,COSAZ
4790      COMMON/RANGE/LRJ,JWIDE,KWIDE,RANGEX,RANGEY
4800      COMMON/CLUTTER/CRRDOT(128),TCRATIO(128)
4810      COMMON/ANTRANS/A11,A12,A13,A21,A22,A11P,A12P
4820      COMMON/ANTENX/ANTX(256,256),NBMAX,CTRWT
4830C
4840C
4850      IF(ICR.EQ.0)GO TO 66
4860C
4870C     DIGITIZE COSINE ANGLE INTO COLUMNS AND ROWS, ROUNDING OFF
4880C     IXCOL.IYROW = COLUMN, ROW NUMBER OF TX AND TY VALUE
4890C     LRECJ = LOGICAL RECORD NUMBER ACROSS TX
4900C     LREC  = LOGICAL RECORD NUMBER DOWN TY
4910C     LREC  = ABSOLUTE LOGICAL RECORD NUMBER IN ANTENNA PATTERN
4920C
4930C     CONVERT FROM NADIR ANGLE CEE TO ANTENNA ANGLE ALPHAX
4940C     CONVERT FROM VEL VECTOR ANGLE ALPHA TO ANTENNA ANGLE ALPHAY
4950C     COSAY = COS(ALPHA)
4960C
4970C     COMPUTE TRANSFORMED DIRECTION COSINES
4980C     TCAX = A21*COSAY+A22*COSAX-A23+COSAZ
4990C     TCAY = A11*COSAY+A12*COSAX-A13*COSAZ
5000C     TCAX = A12P*TCAY+A11P*TCAX
5010C     TCAY = A11P*TCAY-A12P*TCAX
5020C     TCAY = ARCOS(TCAX)
5030C     TCAY = ARCOS(TCAY)
```

A1-8

```
      ALPHAX = TAX
      ALPHAY = TAY

C     CHECK FOR LOOK ANGLES BEYOND AVAILABLE DATA COVERAGE AREA
      TESTX=TCAX-TMINX
      TESTY=TMAXY-TCAY
      IF((TCAX.GT.TMAXX).OR.(TCAX.LT.TMINX)) GO TO 822
      IF((TCAY.GT.TMAXY).OR.(TCAY.LT.TMINY)) GO TO 822
      XCOL = TESTX*(FLOAT(JWIDE)-1.)/RANGEX+1.8
      IXCOL = XCOL
      YROW = TESTY*(FLOAT(KWIDE)-1.)/RANGEY+1.8
      IYROW = YROW

C     FIND THE LOGICAL RECORD LOCATION OF THE LOOK ANGLE
      LRECJ = INT((FLOAT(IXCOL)-1.)/16.)+1
      LRECK = INT((FLOAT(IYROW)-1.)/16.)+1
      LREC = LRECJ+LRJ*(LRECK-1)

C     IACOLJ, IAROWK = COLUMN, ROW IN EACH LOGICAL RECORD
      IACOLJ = MOD(IXCOL,16)
      IAROWK = MOD(IYROW,16)
      IF (IACOLJ .EQ. 0) IACOLJ=16
      IF (IAROWK .EQ. 0) IAROWK=16
C     IA = ABSOLUTE POSITION WITHIN EACH LOGICAL RECORD
      IA = IACOLJ+(IAROWK-1)*16

C     DETERMINE MULTIPLYING FACTOR FROM LOGICAL RECORD
      CRRDOT(J) = ANTX(LREC,IA)**4*CRRDOT(J)

C     SET TARGET TO CLUTTER RATIO TO INFINITY FOR ZERO CLUTTER
      TCRATIO(J)=10.*ALOG10(TPWR*CTRWT/CRRDOT(J))
      GO TO 93
  56  TCRATIO(J)=999.0
      CRRDOT(J)=0.0
      ICR=0
  93  IF(ICT.NE.1) GO TO 792
      CRRDOT(J)=-TCRATIO(J)+300.0
      IF (TRATIO(J).GT.CRRDOT(J))0.0
      CONTINUE
      RETURN
      RETURN
      END
```

APPENDIX - II

Listing of Program RANGE

```
0010C     PROGRAM TO DIVIDE THE EARTH INTO EQUALLY SPACED
0020C     RANGE BINS AS SEEN FROM AN ELEVATED PLATFORM
0030C
0040C     VARIABLES:
0050C     RE   = RADIUS OF THE EARTH
0060C     HGT  = ALTITUDE OF THE PLATFORM ABOVE THE EARTH'S SURFACE
0070C     RMAX = MAXIMUM RANGE (HORIZON)
0080C     DELR = DISTANCE BETWEEN RANGE BINS
0090C     CEL  = ELEVATION ANGLE
0100C     GRAZ = GRAZING ANGLE
0110C
0120C
0130C     =========================================
0140C         D A T A   S E C T I O N
0150C     =========================================
0160C
0170C     DIMENSION CEE(128),R(128),GRAZ(128)
0180C     DATA PI/3.1415927/,RE/6371000./,HGT/
0190C
0200C     CHARACTER*3 RESP3,Y,N
0210C     DATA N/1HN/,Y/1HY/
0220C
0230C     WRITE(06,1020)
0240C     ALTI=HGT/1852.0
0250C     WRITE(06,1000)"ALTITUDE =",ALT1," NM"
0260C     WRITE(06,1000)
0270C
0280C     WRITE(06,1000)"DO YOU WISH TO CHANGE THE
0290C     WRITE(06,1000)" CIRCULAR ORBIT ALTITUDE ?"
0300C     WRITE(06,1000)" "
0310C     WRITE(06,1000)"ENTER Y OR N"
0320C     READ(05,1000)RESP3
0330C     IF(RESP3.EQ.N) GO TO 14
0340C     WRITE(06,1000)" "
0350C
0360C
0370C
0380C     WRITE(06,1000)"INPUT THE NEW ALTITUDE IN NM"
0390C     READ(05,1000)HNM
0400C     HGT=HNM*1852.0
0410C  14 CONTINUE
0420C
0430C     =========================================
0440C        P R O G R A M   S E C T I O N
0460C     =========================================
0470C
0480C     RESO=RE**2
0490C     RHITSO=((RE+HGT))**2
0510C     ...
0520C     ...
0530C     ...
0540C     COMPUTE SPACINGS SUCH THAT THE LAST RANGE BIN IS NOT AT THE HORIZON
0550C     DELR=(RMAX-HGT)/128.0
0560C
0570C     SET UP OUTPUT TABLES
```

```
0590C
0600      WRITE(06,1000)" "
0600      WRITE(06,1000)"ALTITUDE   =",HGT," METERS"
0610      WRITE(06,1000)"RMAX,"      METERS"
0620      WRITE(06,1000)"RMAX,"     METERS"
0630      WRITE(06,1000)"CEEMAX     =",CEMAXDEG," DEGREES"
0640      PRINT 1000
0650      PRINT 1009
0660C     WRITE(06,1000)" "
0670C
0680 1000 FORMAT(V)
0690 1009 FORMAT(3X,"I",7X,"RANGE(I)",9X,"CEE(I)",10X,"GRAZ(I)")
0700 1010 FORMAT(I4,2X,1P1E16.7,2P2E16.7)
0700C
0710C     CALCULATE ELEVATION ANGLE CEE FOR EACH RANGE INCREMENT
0720C     AND GRAZING ANGLE GRAZ
0730C
0740C     THE FIRST ELEVATION ANGLE IS NORMAL TO THE EARTH
0750C     CEE(1)=0.0
0760C
0760C     DO 60 I=1,120
0770      R(I)=HGT+(FLOAT(I-1)*DELR)
0780C
0790C     IF(I.EQ.1) GO TO 53
0800      CEE(I)=ARCOS((-RESQ+(R(I)*R(I))+RHTSQ)/
0810     (2.*R(I)*(RE+HGT)))
0820C
0830C     COMPUTE THE GRAZING ANGLE
0840      GRAZ(I)=ARCOS(((RE+HGT)/RE)*SIN(CEE(I)))
0850      GRAZDEG=GRAZ(I)*180.0/PI
0860   53 CEE(I)=CEE(I)*180.0/PI
0870      WRITE(06,1010)I,R(I),CEEDEG,GRAZDEG
0880   60 CONTINUE
0890      STOP
0900      END
```

APPENDIX - III

Listing of Program SCAN

```
PROGRAM TO COMPUTE SCAN ANGLES OF EQUALLY SPACED
DOPPLER BINS AS SEEN FROM A MOVING PLATFORM

VARIABLES:

RE    = RADIUS OF THE EARTH
HGT   = ALTITUDE
VEL.  = VELOCITY
ALAM  = WAVELENGTH
RMAX  = MAXIMUM RANGE
DELTAR = DISTANCE BETWEEN RANGE BINS
DELCR = RANGE BIN WIDTH
DELF  = DISTANCE BETWEEN DOPPLER BINS
DELTF = DOPPLER BIN WIDTH
ALPHA = ANGLE B/N VELOCITY VECTOR AND VECTOR TO POINT ON GROUND
ALPHAM = MINIMUM ANGLE ALPHA
SF    = SCALE FACTOR
CEE   = ANGLE MEASURED FORM NADIR
XLAT  = SUBLATITUDE POINT OF SATELLITE
XINC  = ORBITAL INCLINATION ANGLE
QUAD  = NORTH OR SOUTH LOOKING QUADRANT
DIRE  = EAST OR WEST ORBIT DIRECTION

****************************************************************

D A T A   S E C T I O N

****************************************************************

      DIMENSION VDOP(128,128),VDE(128,128),VDS(128,128)
      DIMENSION CEE(128),ALPHA(128),R(128),VDS(128,128)
      DATA PI/3.14159277,RE/▮▮▮▮/,HGT/▮▮▮▮/,GRAZ(128)
      XLAM/.24/,DELTAR/78./,DELTF/20./,SF/1.0E30/
      CHARACTER*3 RESP,N,S
      CHARACTER*3 RESP2,E,W
      CHARACTER*3 RESP3,Y,N
      DATA N/1HN/,V/1HV/,S/1HS/,E/1HE/,W/1HW/

      WRITE(06,1000)"    "
      ALTI=HGT/1852.0
      WRITE(06,1200)ALTITUDE   ="ALTI."  NM"
      WRITE(06,1040)"DO YOU WISH TO CHANGE THE CIRCULAR ORBIT ALTITUDE ?"
      WRITE(06,1040)"ENTER Y OR N"
      READ(05,1060)RESP3
      IF(RESP3.EQ."Y") TRANSITION ALTITUDE
      IF(RESP3.EQ."N") GO TO 14
      WRITE(06,1040)"INPUT THE NEW ALTITUDE IN NM"
      READ(05,1080)HGT
```

```
0530  HGT=HNM*1852.0
0540  VEL=1.9J76E07*SQRT(1/(HGT+RE))
0550C FOR ALTITUDES LESS THAN 90 NM. ASSUME AIRBORNE PLATFORM
0560C   IF(HNM.GT.90.0) GO TO 81
0570C   WRITE(06.1000)"INPUT AIRCRAFT'S GROUND SPEED IN KNOTS"
0580C   READ(05.1000) GS
0590  QUAD=P.0
0600  DIRE=0.0
0610  XLAT=0.0
0620  XINC=0.0
0630  VEL=GS*0.0144444
0640
0650  WRITE(06.1000)"GROUND SPEED =".VEL." M/S"
0660  GO TO 14
0670  81 WRITE(06.1000)"ALTITUDE =".HGT." METERS"
0680  WRITE(06.1000)"ORBITAL VELOCITY =".VEL." M/S"
0690
0700  14 CONTINUE
0710C   WRITE(06.1000)" "
0720
0730  81 INPUT SATELLITE ORBIT DATA
0740C   BYPASS SATELLITE DATA IF AIRBORNE PLATFORM
0750C   IF(HNM.LT.90.0) GO TO 89
0760  WRITE(06.1000)"INPUT SATELLITE INCLINATION ANGLE "
0770  WRITE(06.1000)"AND INSTANTANEOUS LATITUDE"
0780  READ(05.1000)XINC.XLAT
0790  XINC=XINC*PI/180.0
0800  XLAT=XLAT*PI/180.0
0810  CINC=COS(XINC)
0820  CLAT=COS(XLAT)
0830  CO=ARCOS(CINC/CLAT)
0840
0850  WRITE(06.1000)"IF FLYING EAST ENTER E"
0860  WRITE(06.1000)"IF FLYING WEST ENTER W"
0870  READ(05.1000)RESP
0880  IF(RESP.EQ.W)DIRE=-1.0
0890  IF(RESP.EQ.E)DIRE=1.0
0900
0910  WRITE(06.1000)"IF LOOKING IN NORTH QUADRANT ENTER N"
0920  WRITE(06.1000)"IF LOOKING IN SOUTH QUADRANT ENTER S"
0930  READ(05.1000)RESP2
0940  IF(RESP2.FQ.N) QUAD=1.0
0950  IF(RESP2.FQ.S) QUAD=-1.0
0960  IF(XINC.LT.0.0) QUAD=-QUAD
0970  89 QD=QUAD*DIRE
0980
0990C ************************************
1000C ************************************
1010C   P R O G R A M   S E C T I O N
1020C ************************************
1030
1040C FORMAT(.V)
1050  RESQ=RE*RE
1060  RH1SQ=(RE+HGT)*(RE+HGT)
1070  RH1=SQRT(RH1SQ-RESQ)
1080  U=ARCOS(RAX-HGT)/128.
1090
1100  ALP=PI/2.-ARSIN(RE/(RE+HGT))
1110  ALPHA=2.(VLI/PAIAM)/128./COS(ALP*AH)
```

```
1188    R(I)=HGT+(FLOAT(I-1)*DELR)
1190    IF(I.EQ.1) GO TO 36
1200    CEE(I)=ARCOS((-RESQ+(R(I)*R(I))+RHTSQ)/(2.*R(I)*(RE+HGT)))
1210    CEE(I)=0.0
1218    BETA=ARSIN((RE+HGT)/RE)*SIN(CEE(I)))
1230    GRAZ(I)=-BETA+(PI/2.0)
1240.C
1250.C
1260.C
1270.C
36
1280.C
1290    WRITE(86,1000)"ENTER THE RANGE BIN NUMBER"
1298    WRITE(86,1000)"TO SEE ALL DOPPLER COMPONENTS AT THAT RANGE"
1300    READ(85,1000)NRAN
1310.C
1320.C COMPUTE EQUATORIAL ROTATIONAL VELOCITY
1330.C AND ASSOCIATED CONSTANTS
1340.C
1350    VE=2.0*PI*DIRE*RE/86400.0
1360    CINC=COS(XINC)
1370    CLAT=COS(XLAT)
1380    CD=ARCOS(CINC/CLAT)
1392    CAM=COS(ALPHAM)
1400    DV2=VE*VE*CINC/CAM
1410    DV3SQ=VE**2*(CLAT**2-CINC**2)/CAM**2
1420    DV3SQ=SQRT(DV3SQ)
1430    VV2=DV3**2*DV3SQ
1440.C
1450.C COMPUTE THE MAX DOPPLER BIN
1460    XJMAX=128.0*SIN(CEE(NRAN))/(VEL*CAM-VE*CINC)
1470    XJMAX=XJMAX*SQRT((DV2**2+DV3SQ))
1480    JMAX=INT(XJMAX)
1490    IF(JMAX.GT.128) JMAX=128
1500.C
1510.C
1520.C
1530    HDG=ARSIN(CINC/CLAT)
1529    HDGDEG=HDG*180./PI
1530.C
1540.C ALPHA LOOP
1550    IV=NP/N
1560    GR=COS(GRAZ(IV))
1570    SINC=SIN(CEE(IV))
1578.C
1580    DO :50 JV=1,128
1590.C DONT COMPUTE FIRST RANGE BIN
1600    IF(IV.EQ.1) ALPHA(IV,JV)=PI/2.0
1610    IF(IV.EQ.1) GO TO 450
1620.C
1630.C COMPUTE FRACTIONAL DOPPLER VELOCITY
1640    DV1=FLOAT(JV)*(VEL*CAM-VE*CINC)/128.0
1650    RT=(DV2**2+DV3SQ)-(DV1/SINC)**2
1660.C
1670.C TEST FOR INVALID ANGLE OFF EARTH
1680    IF(RT.LT.0.0) GO TO 450
1690    SQTV=SQRT((RT)*QD
1700    XNDR=DV1*DV2-DV3*SINC*SQTV
1710    ALPHA(IV,JV)=ARCOS(XNDR/VV2)
1720.C
1730.C COMPUTE SCAN ANGLE
1740    SCAN=ARCOS(COS(ALPHA(IV,JV))/SINC)
1750    SCANDEG=ALPHA(IV,JV)*180.0/PI
1760.C
1770.C COMPUTE SATELLITE DOPPLER COMPONENT
1780    DDS(IV,JV)=VEL*ARCOS(ALPHA(IV,JV))
1790.C
1800.C COMPUTE EARTH DOPPLER COMPONENT
```

```
1820    VDE(IV,JV)=VE*GR*COS(SCAN-CD*QUAD)*CLAT
1830C   COMPUTE TOTAL DOPPLER COMPONENT
1840C   VDOP(IV,JV)=VDS(IV,JV)-VDE(IV,JV)
1850
1860
1870C
1880C
1890C
1900C*********************************************************
1910C   O U T P U T   S E C T I O N
1920C*********************************************************
1930C
 450    CONTINUE
1940    WRITE(96,1900)" "
1950    WRITE(96,1920)"VECTOR HEADING  =",HDGDEG," DEGREES"
1960    WRITE(96,1900)" "
1970    PRINT 1904
1980 1904 FORMAT(3X,"J",7X,"ALPHA(I,J)",7X,"SCAN(I,J)",7X,"VDOP  KTS")
1990    WRITE(96,1000)" "
2000C
2010    DO 452 JP=1,JMAX
2020    ALPHADEG=ALPHA(NRAN,JP)*180.0/PI
2030    VDE(NRAN,JP)=-VDE(NRAN,JP)
2040    SCANR=ARCOS(COS(ALPHA(NRAN,JP))/SINC)
2050    SCAN=SCANR*180.0/PI
2060    VKTS=VDOP(NRAN,JP)*1.9438445
2070    WRITE(96,1003)JP,ALPHADEG,SCAN,VKTS
2080 1003 FORMAT(14,2X,2P2E16.7,1P1E16.7)
2090C
 452    CONTINUE
2100    GRAZDEG=GRAZ(NRAN)*180.0/PI
2110    CEDEG=CEE(NRAN)*180.0/PI
2120    VDMAX=VEL*(CAM-VE*COS(XINC))
2130    WRITE(96,1000)" "
2140    WRITE(96,1000)" "
2150    WRITE(96,1020)" "
2160    WRITE(96,1040)" "
2170    WRITE(96,1000)"        I        GRAZDEG       CEDEG
                        VDMAX"
2180    WRITE(96,1000)" "
2190    WRITE(96,1000)NRAN,GRAZDEG,CEDEG,VDMAX
2200    WRITE(96,1000)" "
2210    SQTVZ=SQRT((DV2**2+DV3SQ))*QD
2220    XNUMEZ=DV3*SINC*SQTVZ
2230    ALPHAZ=ARCOS(XNUMEZ/(DV2**2+DV3SQ))
2240    SCANZ=ARCOS(COS(ALPHAZ)/SINC)
2250    ALPHADEZ=ALPHAZ*180./PI
2260    SCANDEZ=SCANZ*180./PI
2270    WRITE(96,1000)"        ALPHA(J=0)     SCAN(J=0)"
2280    WRITE(96,1000)"      ALPHADEZ,SCANDEZ "
2290    WRITE(96,1000)" "
2300    WRITE(96,1000)" "
2310    STOP
2320    END
```

APPENDIX - IV

Glossary

$ANT(T_x, T_y)$    Antenna pattern weighting function.

$A_x$        Polar angle from X axis.

$A_y$        Polar angle from Y axis.

$A_{yd}$      Polar angle from Y axis with doppler increment included.

$A_{ymin}$   Minimum Y axis angle which intersects the horizon.

$C(I)$      Elevation angle as a function of range.

$C_{max}$     Maximum elevation angle which intersects the Earth.

$C(r,\dot{r})$     Clutter intensity scatter function, dependent on range and doppler.

$D_f$        Frequency separation of consecutive doppler bins.

$D_r$        Range separation of consecutive range bins.

$F_d$        Two way doppler shift of radar echo.

$G(I)$      Grazing angle as a function of range.

$H$          Height of radar platform above the Earth's surface.

inc        Satellite orbit inclination angle.

Isodop   Locus of equal doppler points on the Earth's surface.

Isorange     Locus of equal range points on the Earth's surface.

lat        Instantaneous satellite subpoint latitude.

$R(I)$      Range as a function of range bin number.

$R_e$        Radius of the Earth.

$R_{max}$     Range of the most distant range bin.

$T_x$        Directional cosine from X axis.

$T_y$        Directional cosine from Y axis.

$V_{diff}$    Velocity differential between successive doppler bins

$V_e$        Equatorial velocity of the rotating Earth.

$V_r$        Radial velocity component of a target.

$V_{rmax}$   Maximum relative radial velocity of the Earth's surface.

$V_p$        Radar platform air/orbital velocity.

$\Delta f$        Doppler filter bandwidth.

$\Delta r$        Range cell resolution width.

# MISSION
## of
## Rome Air Development Center

*RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence ($C^3I$) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.*